Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnline CONFERENCE PAPER ARCHIVE

IFAC-PapersOnLine 49-30 (2016) 144–149

Method for Design and Performance Evaluation of Ad Hoc Networked Mobile Robotic Systems using OMNET++

Daniel C. Ramos*   Ubirajara F. Moreno*
Luis Almeida**

*Federal University of Santa Catarina, Automation and Systems Department
Florianopolis, Brazil (e-mail: daniel8484@gmail.com; ubirajara.f.moreno@ufsc.br).
**Telecommunication Institute, Faculty of Engineering, University of Porto
Porto, Portugal (e-mail: lda@fe.up.pt)

Abstract: Using a team of mobile robots connected through ad hoc networks is becoming increasingly attractive for a myriad of applications, including search, rescue and surveillance. In this paper, we present a method for the design and performance evaluation of complex wireless networked control systems, focusing on cooperative control strategy in robotic tasks. It is described a simulation architecture and specific developments that are required to simulate cooperative robotic systems over a mobile ad hoc network (MANET), regarding individual control, cooperative control, network model and topology control aspects. We assess the capabilities of the proposed method using OMNET++/INET simulator and a *rendez-vous* task with topology control over a MANET. The *rendez-vous* task is implemented as a consensus problem and is solved by receding horizon control. The resulting simulation shows that not only it is possible to simulate this complex set of algorithms on OMNeT++, but if an organized simulation process is followed, it may allow a better planning of experimental cases to achieve more meaningful results.

Keywords: Networked Control Systems (NCS); Mobile Ad Hoc Network (MANET); Cooperative Robotics; System Simulation; Wireless Sensor Network (WSN), OMNET++.

1. INTRODUCTION

In recent years, we have witnessed an increasing use of teams of mobile robots in cooperation scenarios in which they are deployed to solve tasks ranging from area coverage to exploration and cooperative transport. In such cases, a cooperative decentralized decision is often desired and built on top of wireless communication networks, which ends up having a significant impact on team behaviour (Ramos, 2015a). Ideally, bandwidth efficient, low latency, and faultless communication is desired. However, in real wireless networks, especially in the case of mobile ad hoc networks (MANET), the bandwidth and communication range are limited, propagation delay exists and increases with the number of hops the information needs to cross, and access collisions cannot be fully mitigated (Oliveira, 2011).

There are several studies addressing these issues in Networked Control Systems (NCS) (Li, 2014; Bauer, 2014), Wireless Sensor Network (WSN) (Tonneau, 2015; Zhang, 2010) and even simple robotic systems (Pohjola, 2008; Kudelski, 2013; Wei, 2014; Sabattini, 2016). These studies essentially rely on a simulation consisting of physical and network parts, achieved by co-simulating with two different simulators (Kudelski, 2013), by expanding a network simulator with physical models, or by expanding the physical simulator with network models (Li, 2014; Mi, 2015).

Concerning the specific network simulator, recent surveys (Pujeri, 2014; Wiengärtner, 2009) show little performance gains when choosing one over another. In this context, OMNeT++ has become a popular choice in different application domains. For example, it was integrated with Matlab to simulate indoor wireless networks (Zhang, 2015), it was used to perform Wireless Sensor Networks (WSN) simulations (Ferrari, 2013) as well as simulations of NCSs (Li, 2014). Thus, we deem OMNeT++ a resourceful tool for different applications and suitable to model real networks. Note that OMNeT++ is not only a discrete event simulator but also a framework that gives the necessary tools to make network simulations, e.g. using INET (INET Framework, 2016). In particular, this framework also allows implementing non-network related algorithms, such as robots' navigation and the cooperative control strategy.

Even though the referred works represent advances in studying the impact of a network on control systems, they lack an organized method to structure complex NCS simulations focused on cooperative robotics. Methods to guide the simulation are constantly being proposed by the scientific community in different fields, as for example, in general model simulation (Law, 2008), in design of Cyber-Physical Systems (CPS)(Jensen, 2011) or in network simulations (Kristiansen, 2015).

Moreover, simulations also prove useful for the purpose of Verification, Validation and Testing (VV&T) allowing an easy exploration of the configuration and operational spaces to achieve the simulation objective. This is shown in recent works on simulation models (Law, 2008; Sargent, 2013) and

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.11.144

agent-based simulation (Klugl, 2008).

In this work we propose a method to design and evaluate the performance of cooperative robots executing a task that is subject to real wireless network characteristics (we call it a Wireless Networked Cooperative Robotic System – WNCRS). We present the design and validation of one recent implementation (Ramos, 2015a), using OMNeT++ to simulate both the network and control strategies. In particular, we use a consensus control strategy combined with predictive control (RHC) (Ordoñez, 2014) for a group of cooperative mobile robots communicating through a MANET that relies on a TDMA-based protocol with loose synchronization (Oliveira, 2011), and a simple topology control. Then, we analyse the impact of the network on a *rendez-vous* task.

In the next section, the overall method is detailed, describing its steps, followed by an implementation example in section 3 and conclusion in section 4.

2. SIMULATION DESIGN AND EXECUTION

The proposed method is an adaptation from previous well known works in VV&T, namely the work from Balci (1995) as a foundation with improvements from recent works (Law, 2008; Sargent, 2013, Law, 2015). The main idea is to develop the simulation in sequential steps, taking in account some particularities of this type of simulation (Fig. 1).

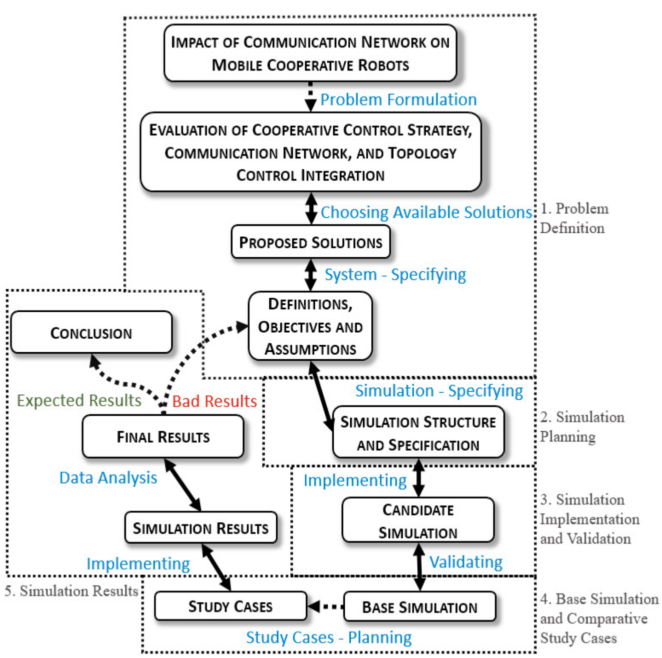

Fig. 1. Proposed method to build a WNCRS simulation study in terms of actions (arrows) and results (boxes). Actions may be directional (dotted) or bidirectional.

These steps are described in the following subsections, according to the dotted boxes shown in Fig. 1.

2.1 Problem Definition

The first step, as proposed in Balci (1995), is to state what is expected from the simulation, or in another words, what kind of problem is going to be the object of study. This is followed by formulating the problem in detail, which consists in defining what type of algorithms are going to be part of the simulation, how they will interact and which task they will perform. With the problem established, is necessary to choose which solution techniques are going to be implemented in the simulation, including at least one solution for cooperative strategy, individual robot control, mobility model, communication network, and for topology control.

It is important to document definitions, objectives and specially the assumptions, which requires special attention as these may not work as expected or have unwanted effects in the results, requiring changes along the implementation.

2.2 Simulation Planning

The next step starts by setting the definitions regarding the simulation. This is also referred as conceptual and communicative modelling (Law, 2015). The first has the objective of guiding the implementation process through an informal creation of diagrams that explain the context and organization of the simulation. The latter aims at documenting, in a textual form, the simulation's most important aspects, aiming the reproduction of the simulation by others.

The main idea here is to set up a base simulation, or in other words, a reliable reference simulation that will be used to simulate specific cases for comparative purpose. For this base simulation to be considered valid, it should keep the main characteristics of a real system (Sargent, 2013). As there are different types of algorithms, it is not a trivial thing to validate all of them at the same time, and it would require a testbed (Patel, 2015) to reproduce real results for validation. Considering this, we assume that if the algorithms were validated individually or if they already been testbed-tested, even if the results are not exact, they should give some indications of the overall behaviour of the system.

Furthermore, it is important to choose a simulator capable of dealing with discrete events or to use co-simulation (Li, 2014). We opt for the former, using the OMNeT++ discrete events simulation framework to simulate the network and extending its capability to deal with cooperative control and mobility models. This is possible because OMNeT++ accepts C++ code and libraries, thus being able to accept translated Matlab code. It also lets us build the simulation in a modular way, making it possible to replace pieces of the code without modifying the entire simulation. With this in mind, the simulation structure was design to be modular, with blocks based on their function (Fig. 2).

This structure provides guidelines when implementing this type of simulation, since it is important to define and organize all the diverse aspects involved in WNCRS simulation. It starts with the definition of cooperative task and system parameters (e.g. number of robots, type of communication and robot and initial conditions). The network branches indicate all the characteristics related to communication: definition of the network using OSI layers, wireless technology used,